YEARLY PROGRESS REPORT

Project Title: Aluminum Carbothermic Technology

Covering Period: July 1, 2001 through June 30, 2002

Date of Report: October 1, 2002 (Revised)

Recipient: Alcoa Inc.

Award Number: DE-FC07-00ID13900

Subcontractors: Elkem ASA, Carnegie Mellon University

Other Partners: Norwegian Research Council

Contact: Marshall J. Bruno, 724-337-1209; 724-337-5548;
marshall.bruno@alcoa.com

Project Team: Thomas Robinson, DOE Washington Headquarters
John Yankeelov, DOE Idaho Operations Office
Seb Klein, DOE Idaho Operations Office

Project Objective: The objectives of this phase of the program are to improve understanding of carbothermic reduction for producing aluminum and to select the most promising options for further evaluation in the 1- to 2 MW pilot-scale research planned for the next phase. Specifically, we would like to demonstrate process operational feasibility in experimental arc furnaces. We have identified several key technical issues to be addressed. These include: effective power delivery, minimizing aluminum losses through volatilization, and recovering acceptable aluminum purity from decarbonization.

Background: The carbothermic reduction concept is not new. Many attempts have been made by individual aluminum companies to produce aluminum by using very high-temperature chemical reduction of alumina or alumina-bearing ores with carbon. From 1971 through 1984, Reynolds conducted research and development on carbothermic reduction of alumina in electric arc furnaces to produce aluminum. They investigated both dc- and ac-type systems in small pilot furnaces (100 to 200 kW). Reynolds demonstrated three phases of operation per metal tap cycle and identified three major hurdles as well. Pechiney, Alcan, and CSIRO also put considerable effort into electric arc carbothermic reduction of alumina. Alcoa too had initiated an effort in this technology. In 1999, we contracted Mintek to conduct electric arc-furnace tests at their

facility in South Africa, to evaluate the effects of arc mode on reactor performance and to initiate a preliminary feasibility assessment of an Advanced Reactor Process (ARP). Given the result of these tests, we then began to assemble a team for further research on this technology.

Status: Program status is presented by task and sub-task areas.

Task 1 : Planning and Management

An Advanced Waiver of Patent Rights was granted to Alcoa by DOE. The Advanced Reactor Process patent was issued in Norway, and the claims for the United States patent application were allowed. DOE amended the contract, designating an additional $999,980 for FY 2002. The Norwegian Research Council committed to funding Elkem for their work on the process over the next two years for a total of approximately $500,000. Progress for the program was reported at the DOE annual technical review meeting in October 2000, and updated at a review meeting with DOE in June 2002. Two abstracts will be submitted to the Aluminum Reduction Symposium group of TMS for papers to be presented in March 2003 at the annual meeting. One paper will compare the Advanced Reactor Process with the Hall-Heroult Process; the second paper will describe the Advanced Reactor Process and provide a status report on progress to date.

Alcoa and Elkem formed a team to study potential business opportunities for the Advanced Reactor Process. Several case studies were identified for further evaluation covering a range of scenarios from smelter feed to a mini-mill operation to a large scale smelting facility on the order of 240,000 metric tons per year Al production. Capital and operating costs are being updated and compared to typical Hall costs, and to the LME price of aluminum.

Task 2 : Determine Fundamental System Properties and Parameters

Task 2.1- Slag Viscosities

As previously reported, Task 2.1 was completed in July 2001 for both slag and metal phases relative to the Advanced Reactor Process. Professor Sridhar Seetharaman from Carnegie Mellon developed mathematical expressions for estimating the viscosities of Al2O3- Al4C3 slag compositions containing up to 0.4 mol fraction of Al4C3 over a temperature range of 1950 C to 2150 C using a model developed by Roscoe for handling two phase regions such as solids suspended in liquid slag. Predicted viscosities were on the order of 0.27 Pa.s at 0.4 mol fraction Al4C3.

Professor Seetharaman also developed an expression for the viscosity of Al- C over a range of C compositions up to 45 weight per cent over a temperature range of 1850 C to 2250 C. For example, the viscosity was 0.0028 Pa.s at 2025 C and 20% C.

The procedures for developing the fundamental expressions were complex. Professor Seetharaman has written a technical paper on the subject, to be published in the November 2002 issue of Journal of Metals, titled "Estimation Models for Viscosities of Molten Slags and Alloys." The viscosity values determined by Professor Seetharaman will be used in dynamic computer models under development (see Task 3).

Task 2.2- Vapor Recovery Reaction Kinetics

The vapor recovery component is a critical factor in the success of the Advanced Reactor Process. Even though the process is designed to minimize volatilization of the Al species, there will be a significant quantity of Al and Al2O vapors that must be processed to recover the energy and Al values represented. The Vapor Recovery Reactor (VRR) is envisioned as a countercurent moving bed column in which the Al gases react with carbon to produce Al4C3, which is returned to stage 2 of the basic reactor to fulfill the stoichiometry required to sustain metal production. It is critical to determine the controlling mechanism for the rate of reaction between carbon, Al and Al2O, both for equipment design purposes and for predicting the effects of system parameters on VRR performance as expressed by the degree of conversion to Al4C3. To measure the rates, an experimental furnace was implemented in which single carbon particles in the form of cylinders, about 25 mm. in diameter by 25 mm. high, are contacted with reaction vapors from stage 1 and 2 reactions. The furnace is induction heated and rated at 65 kW heat input. It is capable of attaining temperatures greater than 2100 C using a carbon or graphite crucible. The crucible is sealed with a lid containing a chimney for venting reaction gases. The particles are suspended from the lid into the reactor freespace.
The starting feed charge to the crucible could be one of several options, including Al2O3-C, Al and C or stage 1 or 2 slag obtained from the large Elkem laboratory reactor. About 5 to 7 kg. of starting material is charged. Various types of carbon media have been subjected to contact by reaction gases for selected time periods, on the order of 10 to 20 minutes. At the end of the test, the particles are rapidly transferred to a cooling chamber to quench them and deter oxidation. Results are based on metallographic analysis of the spent particles. SEM photographs clearly show the presence of Al4C3 and the degree of reaction based on the position of the reaction front within the particle pores, as well as the thickness of carbide on the surface of the carbon particle. Phases are analyzed by EDX.

Chemical analyses and XRD have also been employed for some tests.
In addition to the single particle tests, several "canister" tests were also made. In these tests, a tube with a closed end containing drilled holes was filled with about 300 grams of carbon media sized at 5 to 10 mm; the tube was positioned inside the "chimney" of the reactor and extended into the reactor freespace to an elevation just above the molten slag level. Reaction gases passed up through the canister before venting. At the conclusion of these tests, the carbon media was carefully removed from the tube in layers and analyzed by SEM. As expected, Al4C3 was present at the entry to the canister where the temperature was highest, with lessening amounts further up the column along with evidence of aluminum oxycarbide formation, changing to Al2O3 at the top of the column where the temperature was lowest and straight condensation occurred. For all tests, the slag temperatures were measured using a Leeds and Northrup single color disappearing filament optical pyrometer, sighting onto the molten slag surface through a sightglass on the crucible lid. For many runs, temperatures were also measured in the freespace above the slag, next to the single particles and embedded inside the carbon filled tubes, using type C tungsten-rhenium thermocouples inside hexalloy protection sheaths. The two methods for temperature measurement agreed to within 10 C.

Gases exiting the reactor were sampled and analyzed by an on-line mass spectrometer capable of analyzing for CO, CO2, N2, Ar, O2, and H2O. The Al containing gases condensed or reacted before entering the mass spectrometer. Ar used for system purges to minimize oxidation of graphite components was metered and used as a tracer gas to determine total volumetric gas flow rate. This enables the quantitative determination of the rate of CO generation, which corresponds directly to the rate of reaction for stages 1 or 2.

A number of candidate carbon media types have been tested to determine reactivity. The carbon was characterized based on bulk density, porosity and average pore size. The SEM results indicated that the reaction rate controlling step is the diffusion of the gases into the carbon materials. The effective diffusivities of Al and Al2O vapors were estimated based on the properties of the gas mixture and the porous media. These values were then used in the computer model for the VRR to predict performance at selected operating conditions, expressed as conversion of Al containing gases to Al4C3. The calculated thicknesses for the carbide layer over the carbon particle predicted from a shrinking core mechanism agreed very well with the experimentally determined thicknesses, consistent with the concept that the reaction rate is diffusion controlled. The experimental results were also the basis for selection of certain carbon types that provided the most effective reaction.

Task 3 : Computer Simulation of Process Parameters

Task 3.1- Process mass and Energy Balances

A total process model is being developed using two different approaches, one employing MatLab software and the other using Aspen/FACT software. The models are in their early stages of development. The MatLab approach has the potential advantage of ultimately interfacing with the independent models being developed for stages 1 and 2 and the VRR. Recent activities related to the Aspen/FACT include upgrade of Aspen software to windows 11.1, purchase of CHEMAPPS software which is needed to implement Aspen/FACT and trouble shooting of the Aspen/FACT program. After much effort, the software installation was debugged and an example problem was successfully run.

Task 3.2- Stage One Model

As previously reported, the initial work on a stage 1 model was being done using CFX 4 computational fluid dynamic software. Some progress was made in coupling current flow, joule heating, heat flow, natural convection and sidewall freezing. However, problems were experienced with CFX`s capability to handle the geometric complexity of the model and it was decided to change software. Two candidate programs are under consideration. One is FemLab, which is currently being used to model stage 2 (see Task 3.4); the other is CFX 5. Pending the success of using FemLab on stage 2, it may be in a user-friendly state before CFX 5 becomes "routine" to use. CFX 5 is definitely capable of addressing the geometric complexities of the model, having the feature of creating its own unstructured mesh.

Task 3.3- Vapor Recovery System Model

VRR models have been successfully developed for single particle, fixed bed and moving bed scenarios using MatLab software. The single particle model was verified against experimental results obtained from the fundamental studies reported under Task 2.2 for the Alcoa 65 kW unit. The fixed and moving bed models were used to predict performances for the Elkem laboratory scale VRR being evaluated under Task 5. As results become available from the on-going tests at Elkem, the models will be verified. For the fixed bed, the model predicted the life of the bed; that is, the amount of time to convert the entire bed to Al4C3 for the given conditions of gas flow and composition, bed height, type and size of carbon media, inlet gas temperature and VRR column diameter. For the moving bed, the model predicted the percent conversion of Al and Al2O to Al4C3 and the percent conversion of the bed to carbide for the same list of parameters plus the carbon media feed rate to the column. Sensitivity studies were done on inlet gas velocities, bed heights, carbon media feed rates and carbon particle size.
The initial modeling work for the VRR was presented by Vianey Garcia-Orsorio from Carnegie Mellon University at the March 2000 annual TMS meeting in New Orleans. The paper was titled "Stage-by-Stage Model for a Vapor Recovery Reactor in a Carbothermic Aluminum Process". Ms. Garcia-Orsorio`s conclusions were as follows: "A stage-by-stage model was used to represent the behavior of the vapor recovery unit. The kinetic model used is controlled by mass transfer diffusion. Its solution leads to an asymptotic solution in the absence of experimental data. With the model, it was possible to estimate the dimensions of the column. It can be seen that the mechanism that controls the height of the vapor recovery unit is the heat transfer between the hot gas leaving the column and the solid entering the column, which means that the heat transfer mechanism is much slower than the mass transfer. "

A second paper co-authored by Ms. Garcia-Orsorio was published in 2001 in the proceedings for a conference on Computational Modeling of Materials, Minerals and Metals Processing. The title is "Dynamic Model for a Vapor Recovery in Carbothermic Aluminum Process". The conclusions from this paper picked up from the first paper and stated that smaller columns lead to poor recoveries; larger columns provide conditions for reversible reactions to take place, ie Al4C3 formed can go back to Al2O3, which is undesirable for the process.

Task 3.4- Stage Two Model

As previously reported, the software was changed from CFX to FemLab version 2.1. A module of an electrode pair was selected for simulation. Dimitrios Gerogiorgis from Carnegie Mellon University published a paper in 2001in the proceedings for a conference on Computational Modeling of Materials, Minerals and Metals Processing titled "A Steady State Electrochemical Simulation Analysis of a Carbothermic Reduction Reactor for the Production of Aluminum". In this paper, he discussed initial results based on the use of FemLab 2.1. He reported that the electric potential and intensity distributions predicted by the model accounted well for the expected electrode superheating. The temperature distribution indicated a superheated region and confirmed that a relatively uniform heating zone could be achieved and sustained in the middle of the reactor

between the electrode tips. Predicted maximum temperatures were higher than expected due to the absence of a convection term.

Dimitrios also identified future challenges for the stage 2 modeling effort in the form of limitations of the model at that point in its development, which were impacted by the accuracy of many assumptions such as neglecting the effects of convection heat transfer and temperature dependence of electrical conductivity, lack of detailed reaction kinetics and need to validate the thermophysical properties of the system. The paper included a section on work done to develop expressions for the slag thermal properties, including density, viscosity, thermal conductivity, electrical conductivity and specific heat. Some experimental data is available for Al2O3 but there is no such data for Al4C3 liquid.
In January 2002, version 2.2 was released. Dimitrios directed his model development to optimizing the FemLab 2.2 solver to better address the complexities involved in the stage 2 model. FemLab 2.2 provides greater accuracy while requiring less computer run time through the implementation of a coarse mesh and quadratic finite elements versus fine mesh and linear elements used in 2.1. Focus has been on the electrothermic components, specifically the V-T (voltage versus temperature) characteristics as they relate to slag conductivity, electrode length and boundary conditions.

In August 2002, FemLab released version 2.3 code which further improves the solver. The combination of quadratic finite element functions and more refined discretization capability provides desirable accuracy for modeling velocity fields in slag movement characterized by high gradients. Boundary layers adjacent to the top and bottom walls of the reactor can be accurately computed. The result has been successful formulation of the Navier-Stokes isothermal flow problem for different inlet velocities and boundary conditions, as well as resolution of the mesh required. This success is a prelude to addressing the non-isothermal flow problem, which is the next step in the model development.

Task 4 : Metal Recovery Methods
Work on this task was initiated in the third quarter with focus on reduction of carbon in the Al product. A review of process options resulted in several approaches to be evaluated, including (1) Al2O3 extraction to form Al2O3- Al4C3 slag; (2) controlled cooling to effect phase separation of solid Al4C3 from liquid Al; (3) phase separation using chloride salts.

Cooling tests were run on metal containing about 2.5% Al4C3. Samples contained in alumina crucibles were taken to 1810 C using the 65 kW induction furnace. Power was then decreased to attain a 10 C/min. temperature reduction. Results of the cooling tests were mixed. In one melt, the Al4C3 particles concentrated in the bottom of the crucible. However, in an adjacent sample, the Al4C3 particles were dispersed throughout the solidified metal. It was expected that Al4C3 would phase separate and concentrate on the surface of the molten Al. The addition of solid scrap Al will be tested as another means of cooling. Also, flotation will be tried as a means to assist particle movement to the metal surface.

Feasibility of Al4C3 extraction by chloride salts was tested using Dow A130F flux. Conditions were 750 C, one hour hold and a 3:1 salt to metal ratio. The results were promising. Up to 65% of the charge was recovered as carbon free coalesced Al, which was at least 79% recovery of the available Al. Additional tests are planned to evaluate a range of salt to metal ratios, salt type and the effect of holding time.
Reports by Reynolds on Al2O3 extraction tests were studied. Reynolds used a mixture of 70% Al2O3- 30% slag (containing 85% Al2O3- 15% CaO), which equates to 95.5% Al2O3- 4.5% CaO. The CaO was added to reduce the melting temperature of the extractant. Starting at an average concentration of 8.4% Al4C3 in the metal, the average final concentration was 2.1% or a 75% reduction. Temperatures during extraction were in the range of 1700 to 1900 C. Recovery of Al was about 50%. Although the addition of CaO was effective in providing a liquid phase extractant, the use of CaO commercially is unlikely since the oxide reduces to Ca which concentrates in the product metal phase. Alumina extraction is desirable, especially if it takes place in the reactor rather than in a separate furnace as patented by Reynolds. A number of concepts have been considered but none have been tested to date.

Task 5 : Evaluation of the Advanced Reactor Process
The major activities in the second year of the development work on the reactor system were directed to the vapor recovery step of the process. A series of Vapor Recovery Unit (VRU) modules were designed , installed and operated to demonstrate the feasibility of the concept and to obtain design information for the VRU part of the integrated system that is scheduled for installation and operation in FY 2003.
Initially, it was critical to establish a reliable test setup that would generate a representative flow of stage1-stage 2 reaction gases to be processed in the VRU, that is, react with carbon media to form Al4C3. The hot box used to develop side wall electrodes was retained as the vapor generator for VRR studies except that it was sealed with a lid. Three of the 4 sides were cooled using copper panels. Five stage 2 test campaigns were conducted in the "hot box" starting in August 2001. Early tests focused on establishing the design and operational validity of the set-up. Reaction gases were directed through a module termed "A" that represented the inlet to a VRR column but that discharged to the flare-vent system for these tests.

The first run was deficient in power available for reaction due to high heat losses from the hot box, especially through the one uncooled wall. Eventually, this wall failed when the alumina refractory lining melted.

For the second test, all walls were cooled and the electrodes were shortened to provide higher slag resistance. About 400 kW of power to the hot box was attained without exceeding the limiting amperage on the electrodes. Although improved, the hot box was still deficient in power required.

For the third test, the electrodes were further shortened and the starting slag level was lowered. During this test, an Al- Al4C3 layer was formed at the electrode level and the electrodes were partially submerged. There was no evidence of shorting and electrode

consumption was minimal. Most of the reaction gases continued to condense on the underside of the reactor lid.

In the fourth test, the cooling panels were raised in height to allow for increased slag depth. This is important because it provides more space between the metal produced and the electrodes to avoid the possibility of shorting. Again, the electrodes were shortened to allow for higher resistance heat input. A new lid was constructed to improve the seal with the hot box, avoid air inleakage and facilitate installation of a plasma torch for preheating. The plasma unit was designed to add about 230 kW to the hot box, to offset heat losses and reduce fume condensation inside the box. At the time of the test, the plasma system was not ready. As an alternative, a propane torch was inserted into the exit pipe going from the hot box lid to the A module. Some additional heat was attained but the condensation problem still existed. Also, it was determined that the sidewall cooling system needed to be extended to include the corners of the hot box.

The final test on the A module was run in March 2002. The plasma torch preheated the module to about 800 C. After 3 hours of operation (with startup being the initiation of power to the sidewall electrodes) the test was terminated due to a high reactor pressure caused by a water leak from the plasma cooling system. Problems were corrected and the run repeated. The test was successful in meeting the objective of getting reaction gases to the vapor recovery inlet and provided much useful data on the operation of the plasma unit, the stage 2 module and the A module for the vapor recovery reactor. During this test, an on-line mass spectrometer was also successfully implemented. Using metered Ar as a tracer in conjunction with the gas analyses provided an estimate of the total gas flow rate. Reactor pressure was also successfully controlled using high temperature ejectors. The next phase of the program was a series of tests on the vapor recovery column, termed module B. This phase was initiated in May 2002 and is on-going. The VRR design included a tangential gas entry and the flexibility of varying bed height. The first test was aborted after several hours in the preheat stage due to a slag eruption caused by excess water going into the reactor from an unplanned dump of the Al2O3- C pellets. In addition, the plasma system experienced some operational problems, although the hot box and column inlet were heated to greater than 1500 C and 900 C respectively. It was also determined that automatic stoking was required to keep the transfer piping from the hot box lid to the VRR open for gas flow.

After employing the modifications, the system ran well regarding the plasma preheat, control of reactor pressure and uneventful feeding of Al2O3- C pellets. Slag was tapped several times and reaction gases did get to the VRR. The run was terminated when the stokers failed mechanically. Although the stokers worked, they were not robust enough to withstand the temperatures. For the next group of tests, the stokers are being modified. In addition, the B module will be equipped to discharge solids on a continuous basis. This will facilitate operating the VRR continuously with a moving bed of carbon media or as a static bed without discharge.

In a parallel effort, conceptual design of the integrated system (to be installed and

operated in 2003) will be started and long lead, critical materials/equipment will be ordered.

Task 6 : Economic Analysis of the Advanced Reactor Process
Two business cases were developed to review the potential financial benefits of the process. One case compared carbothermic to greenfield Hall-Heroult. The second comparison was with purchase of metals on the LME. These studies used capital and operating costs estimates done in 1999. Results of the comparisons were favorable to carbothermic. Sensitivity analyses identified the most critical parameters that impact the economics. For the Hall-Heroult comparison, the number of years to scale up to full commercial capacity was most significant, followed by the capital cost. For the LME comparison, the most important parameter was the average LME price, again followed by the carbothermic capital cost.

Elkem initiated an upgrade of the cost estimates for the process, including co-generation concepts for effective utilization of the CO by-product gases. The latest capital cost estimate is lower than the 1999 value, although the accuracy is still considered only +/- 50 % at this point in the process development. Capital and operating cost estimates of the Advanced Reactor Process are on-going as new and/or better information becomes available from the experimental results obtained.

Alcoa is exploring potential opportunities for commercialization of carbothermic in the United States, including automotive, extrusion and smelting applications. Scenarios being considered include smaller carbothermic reactors to supply Al to "mini-mill" type applications for casting plants in the range of 15,000 to 25,000 mt/yr production. Rolling mills can range from 14,000 mt/yr to 180,000 mt/yr. Extrusion plants also have a wide range of productivity, up to about 80,000 mt/yr. On-site smelting at a fabrication plant will save transportation costs to ship ingot plus the melting costs. This can be a 3 to 5 cent/lb savings. Also, power contracts are generally more available and lower cost for smaller segments of purchased power.

Plans for Next Year: Program activities planned for fiscal year 2003 are summarized by task.

Task 1: Planning and Management

- Invention reports will continue to be submitted for all novel ideas/concepts associated with the process design and operation, including metal recovery technologies. Where appropriate, patent applications will follow.
- Papers will be presented at the 2003 annual TMS meeting and published in Light Metals. Three papers are scheduled in the Smelting Reduction Technology session and will cover the following: modeling progress on the stage 2 model; a comparison of the Carbothermic Advanced Reactor Process to the Hall-Heroult Process relative to energy, environmental and cost parameters; and a progress report on the development status for the process for the first two years of the contract.

- The business team will continue to evaluate different cases for commercial application of the process, with the impetus being provided by updated capital and operating cost estimates developed under Task 6.
- Potential additional and/or continued funding sources will be sought to cost share future work on the project as it advances to Phase 2 of the development program.

Task 2: Determine Fundamental System Properties and Parameters

- Fundamental studies will be completed for the vapor recovery reaction kinetics with emphasis on determining the driving force for the gas-solids diffusion, i.e. the partial pressures of Al and Al2O vapors at system operating conditions.

Task 3: Computer Simulation of Process Parameters

- At least one version of the total process model will be completed and used as input to the cost model for capital and operating cost estimates under Task 6. It is planned to verify the model based on test results from the integrated reactor system late in fiscal year 2003 or at the start of fiscal year 2004. The model is expected to provide predictions of the effects of trace impurities on reactor performance.

Task 4: Metal Recovery Methods

- Priority will be directed to the alumina extraction method as part of the integrated reactor system, if possible. Bench scale tests will also be conducted in the 65 kW furnace to evaluate important parameters.
- Cooling tests, including the use of flotation assist, will be run on integrated system metal product in addition to more bench scale experiments.
- Further definition of an optimum salt leaching method may be attained on the bench scale equipment, investigating the effects of salt type, salt to metal ratio, temperature and time on metal purity and recovery.

Task 5: Evaluation of the Advanced Reactor Process

- Work will continue through the first quarter of fiscal year 2003 to generate data and understanding of the vapor recovery reactor using the hot box as a gas generating stage 2 module. Several equipment features will also be evaluated, including sidewall electrode slipping, improved electrode seals and use of CO as a plasma preheat gas.
- Concept design, engineering design and procurement of equipment and materials will be aggressively conducted for the integrated reactor system.
- Site preparation for the integrated reactor system will be initiated in the second quarter. Completion of the system installation is scheduled for the end of the third quarter.
- The 3 MW reactor, including stages 1, 2, and the vapor recovery reactor will be operated in two week campaigns starting in the fourth quarter and continuing into the first quarter of fiscal year 2004.

Task 6: Economic Analysis of the Advanced Reactor Process

- Work will continue on upgrading the capital and operating cost estimates. Revised estimates will be applied to the business case studies for a range of reactor production capacities to meet metal supply requirements for the various fabricating operations under consideration.
- Fern Engineering, Inc. will be retained to conduct a conceptual study of energy integration options for the Advanced Reactor Process. Results will be incorporated into the flow sheets used in the capital and operating cost estimates.

Patents:

1) Method and Reactor for Production of Aluminum by Carbothermic Reduction of Alumina; USSN 09/862,192; Filed May 21, 2001; Johansen et al.
2) Method for Recovering Aluminum Vapor and Aluminum Suboxide from Off-Gases During Production of Aluminum by Carbothermic Reduction of Alumina; USSN 09/862,196, Filed May 21, 2001, Lindstad.

Milestone Status Table:

Identification Number	Description	Planned Completion Date	Actual Completion Date	Comments
1.0	Planning and Management	12/31/03		
2.2	VRU Kinetics	12/31/02		Vapor pressure studies initiated
3.1	Total Process Model	10/31/03		
3.2	Stage 1 Model	10/31/03		
3.3	VRU Model	02/15/02		Test against VRU module results in Sept. 2002
3.4	Stage 2 Model	10/31/03		
4.0	Metal Recovery Methods	12/31/02		Small scale tests initiated
5.1/5.2	Module Tests, Electrodes/Panels, Operation	06/15/01	06/29/01	Final reports issued
5.3	Engineering Design for Stage 1/2/VRU Integrated System	02/10/03		
5.5	Build Stage 1/2/VRU Integrated System	05/30/03		
5.9	VRU Module Tests	11/30/02		Equipment mods in progress for Sept. test
5.6, 5.12 - 5.15	Stage 1/2/VRU Test Campaigns (5)	12/26/03		
6.0	Economic Analysis	11/30/03		Capital cost estimate updated
7.0	Final Report	12/31/03		

Budget Data:

Phase/Budget Period	Approved Spending Plan			Actual Spent to Date		
	DOE Amount	Cost Share	Total	DOE Amount	Cost Share	Total
Budget Year 1	678,581	678,581	1,357,162	678,581	1,474,355	2,152,936
Budget Year 2	1,745,086	1,745,086	3,490,172	1,657,586	1,657,586	3,315,172
Budget Year 3 (YTD)	1,322,624	3,300,000	4,622,624	1,322,624	1,341,673	2,664,297

Spending Plan for the Next Year:

Month	Estimated Spending
October 2002	302,432
November 2002	324,515
December 2002	1,846,196
January 2003	367,976
February 2003	500,553
March 2003	241,432
April 2003	227,100
May 2003	323,563
June 2003	142,204
July 2003	141,202
August 2003	361,428
September 2003	251,976